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FINAL DEGREE PROJECT

TÍTLE: Study of the economical effects of airways and directs using NEST.

DEGREE: Air Navigation Engineering

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DATE: July 19th 2016

TÍTOL: Study of the economical effects of airways and directs using NEST

TITULACIÓ: Grau en Enginyeria d'Aeronavegació

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Resum

Aquest treball de fi de grau es centra en analitzar els efectes econòmics i la diferència de costos aplicats a les aeronaus per sobrevolar espais aeris al utilitzar directes en lloc de rutes convencionals, concretament centrant-se en les operacions que comporten un creuament en les fronteres d'espais aeris. Aquest anàlisi avalua les dades de trànsit dels vols realitzats en l'espai aeri europeu durant Febrer i Març de 2016 a través del software NEST.

L'objectiu troncal del treball té com a finalitat trobar els beneficis que s'obtindrien canviant la situació actual, on la majoria de directes es realitzen sota autorització prèvia del controlador aeri, a una plena implementació de les directes a la xarxa de rutes que permeti als usuaris de l'espai aeri introduir aquest tipus d'operacions en els seus plans de vol.

Fonamentalment s'han realitzat dues tasques per assolir l'objectiu del projecte. D'una banda, trobar i avaluar diverses directes amb creuament d'espai aeri que es realitzin amb freqüència, i calcular l'estalvi que suposaria la seva publicació a les cartes aeronàutiques. D'altra banda, a partir d'alguns d'aquests casos, concretament els que impliquen un major estalvi, formular una proposta formal d'aplicació tenint en compte tots els requisits necessaris que comporten la seva introducció.

Pel que fa a les conclusions del treball, s'han constatat alguns aspectes ja previstos, com que diàriament es realitzen una gran quantitat de directes al llarg de l'espai aeri europeu. No obstant, el principal problema és que la majoria d'aquestes no estan publicades a la xarxa de rutes. Aquesta situació, i especialment quan es realitzen directes amb creuament d'espai aeri, implica un augment innecessari de la càrrega de treball dels controladors aeris, que en alguns casos podria posar en perill la seguretat de les operacions. D'altra banda, s'ha trobat que la publicació d'aquest tipus de directes implicaria en la majoria dels casos una reducció de les tarifes de ruta, aquesta reducció seria beneficiosa per als usuaris de l'espai aeri, però perjudicial per als proveïdors de serveis de navegació aèria.

Finalment, amb l'objectiu de modernitzar l'espai aeri europeu i amb això augmentar els beneficis econòmics obtinguts per totes les parts interessades, es proposa una solució imparcial. Aquesta solució seria augmentar les tarifes aplicades per l'ús directes que comportin un canvi d'espai aeri, així obtenint

una situació beneficiosa per a ambdues parts, ja que els proveïdors de serveis de navegació aèria mantindrien els mateixos ingressos de facturació per els costos de ruta i usuaris de l'espai aeri reduirien el combustible consumit i temps de vol.

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Overview

This final degree project analyses the economic effects and the en-route charges difference billed to the airspace users when using directs instead of conventional routing, concretely focusing on the cross-border operations. This analysis assesses the traffic data of the flights performed in the European Airspace during February and March of 2016 by means of the software NEST.

The main purpose that is pursued is to find out the benefits that would be obtained by changing the current situation, where most directs are done under air traffic controller clearance, to a full implementation of the directs in the routes network which would enable the airspace users introduce these operations in their flightplans.

The main tasks of the project accomplished to achieve the objective are fundamentally two. On the one hand, find and evaluate several cross-border directs frequently performed, and compute the savings that would suppose its publication in the airspace charts. On the other hand, from some of these cases, the ones that involve more savings, make a formal proposal of implementation, bearing in mind all the necessary requirements that their introduction have to fulfill.

Regarding the conclusions of the work, it has been confirmed some aspects already expected, like the huge amount of directs that are performed everyday along the European Airspace. However, the main issue is that most of them are not published in the route network. This situation, and specially when performing cross-border directs, implies an unnecessary increase of the air traffic controllers workload which could endanger the safety of the operations. Moreover, it has been found that the publication of cross-border directs would imply in most of the cases a reduction in en-route charges which would be beneficial for airspace users but detrimental for the air navigation service providers.

Finally, aiming to modernize the European airspace and with this increase the economic benefits of all the stakeholders, it is proposed an impartial solution. This solution would be to increase the charges applied for the use of cross-border directs, this situation would be beneficial for both parties because air navigation service providers would keep the same billing income and airspace users would reduce fuel consume and the flight time.

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INTRODUCTION

For years air traffic in Europe has been constantly increasing, due to this fact the capacity of European airspace is reaching its limits. Indeed, in European airspace took place more than 9.7 million flights during 2015, which equals to around 26,650 flights every day [22],and the forecasts say that this traffic rise will continue during the following years. The operation of these aircraft resulted in €766 billion in economic benefits to Europe [1]. However, the slow modernization of airspaces across Europe is being detrimental to the growth of these benefits.

Aiming to improve this situation in the European air network the Single European Sky ATM Research (SESAR) project was launched in 2004. It seeks to meet farther requirements by means of research and development of air traffic management (ATM) solutions. In this context and regarding en-route operations one of these solutions started to be implemented, direct routing (DCT).

DCTs are direct air-segments between two navigations points that avoid using conventional defined routes. Directs can be a previous step to the implementation of a Free Routing Airspace (FRA), or for complex airspaces that cannot apply FRA an opportunity to enhance its airspace.

Nowadays, the use of these routes is widely extended. Even more, there are many studies supporting a greater use of them due to the increase in flight efficiency that suppose the use of DCTs [2][3][23][24]. These analysis conclude that when performing DCTs instead of conventional routing it is achieved a reduction in fuel use, CO_2 and NO_x emissions and flight time, which would mean an increase on the benefits previously mentioned.

Despite the fact of this widely extended use, the majority of the DCTs are not defined in the European route network. The introduction of one type of DCTs to it, the ones that imply a change of airspace during its course, it would probably involve savings in the air navigation service providers (ANSPs) charges. These charges are fees that an aircraft has to pay for overflying a country due to the use of air navigation services that it offers, its price is different and established for each country in Europe.

From this situation comes the aim of this project, evaluate the economic effects and the charges difference in cross-border operations between the use of DCTs and conventional routing, because ANS charges are a non-negligible operational cost (sometimes higher than 10%) for airspace users, especially when fuel costs are low[4].

When defining the project objective it is necessary to distinguish between two main tasks:

- Find and evaluate cross-border DCTs, and compute the savings that would suppose the introduction of them to the route network through the NEST software.
- Propose a possible solution for each case, and once found several DCTs check if the proposals made have a feasible implementation using a NEST function.

The project structure tries to respond as far as possible to the objective detailed above. In the first part, before the main analysis, are described some theoretical concepts and necessary backgrounds in order to make understandable the main analysis. Then, it is introduced the software used (NEST), besides, some of its functions are explained briefly. Once explained the theoretical basis, the main part is developed, the analysis and proposal of DCTs. Finally, the different conclusions of the project are exposed, which try to respond as far as possible to the initial objective.

CHAPTER 1. EUROPEAN AIRSPACE

1.1. Introduction

The European airspace is formed by the sky above the land and sea areas within Europe, it has some elements to understand how it works. This chapter aims to collect all of them in a synthetically and at the same time a knowledgeably manner. It is also to introduce and contextualize the central part of the work, which has a direct and / or indirect relationship with many of the aspects that will be explained in this chapter.

1.2. Network planning

The network planning is a process that tries to enhance the capacity, amount of aircraft handleable during a limited period of time, of the air traffic network (ATN) through forecasting future number of flights and their distribution within the network [27].

It is based in medium/long-term actions, these actions anticipate the demand to avoid capacity imbalances. However, it is also needed agility to solve issues that can come up in an efficient way. The key elements of the ATN continuously improved to meet capacity requirements of en-route operations are: airspace and air route network

1.2.1. Airspace

An airspace is the space lying above a certain area of land or water that belongs to a country according to the right of its sovereignty. As defined by the International Civil Aviation Organization (ICAO) in its Annex 11 [5], the airspaces shall be classified by the air traffic services (ATS) provided in it as:

- Controlled airspace: Class A, B,C, D and E
- Uncontrolled airspace: Class F and G

Controlled airspaces class A are the ones where the four services of ATS (air traffic control (ATC), air traffic advisory (ATA), flight information service (FIS) and alerting service (AS)) are fully provided, these airspaces are mostly used by commercial aviation during en-route phase.

Regarding en-route operations, if the airspace is too big, it is commonly divided in flight information regions (FIRs), specifically for en-route operations in upper flight information regions (UIR). This measure is done to increase airspace capacity, avoiding bottlenecks due to a workload overcharge of air traffic control officers (ATCOs). Moreover, it exists another subdivision of the airspace with the same purpose as the FIRs, the sector which is the primary component of the airspace structure. A flexible sectorization contribute to reduce the workload of the ACTOs during traffic peaks helping to accommodate more flights.

1.2.2. Air route network

Aircraft fly through the airspaces following pre-planned routes, much like highways on the ground. These “highways” called airways are set by the state civil aviation authority and published in its aeronautical information package (AIP), concretely in the en-route charts (ENR) part.

The ENR is formed by waypoints linked by airways, these constitute routes within the airspace and are connected with other airspaces via waypoints called entry/exit points located in its borders. Cross one of this bordering points imply entering in another route network and with this a change in who provides ATS. These two defining features, waypoints and airways, are detailed below:

1.2.2.1. Waypoint

Waypoints, also called navigation points (NAV points), are reference points in physical space used to help the navigation of the aircraft through the air. There are two types, on one hand, the ones used only when applying visual flight rules (VFR) that can be any representative landmark as mountains, buildings, etc. On the other hand, the NAV points located using radio navigation systems which can only be used for flights based in instrumental flight rules (IFR). However, airways can only be created by linking waypoints positioned with navigation aids, so that, the air route network is only defined through this type of waypoint.

NAV points defined by radio aids have a registered name limited to a maximum of five characters. Most of the waypoints distributed over an airspace and its borders have a unique name, although these names sometimes are repeated, this is done in order to avoid mistakes when planning routes. These names are assigned by the aviation authority of the country where the waypoints belong.

1.2.2.2. Airway

As defined by ICAO is a control area or portion thereof established in the form of a corridor equipped with radio navigation aids [6]. These radio navigation aids differentiate airways between: RNAV airways if used following fixed geographic coordinates with satellite navigation systems (GPS) and conventional airways if determined by means of ground-based radio transmitter navigational aids.

An airway may be of single or double direction of flight, which means that an airway may be flown in one direction or in both. In the en-route charts it is depicted whether an airway has single or double direction of flight, in case of single direction, an arrowhead is pointing the correct direction of flight. Moreover, normally, all airways have a MEA (Minimum En-route Altitude), which is the minimum allowed level to fly that airway ensuring clearance over obstacles and are distinguished between odd or even depending on the flight levels that have to be used while flying on it [25]. The following figure (figure 1.1) shows an example of an ENR chart with airways joining waypoints:

Figure 1.1 Aeronautical chart example [26].

A good planning of the airways network makes the difference between achieving an optimum and efficient airspace design or not, it has to offer a wide range of routes for its users without compromising the capacity. However, when planning the route network, it have to be considered that ICAO rules for aeronautical charts [7] do not allow airways longer than 200NM without having waypoints within it, i.e. if it is wanted an airway of 450NM there have to be two NAV points on the way between the initial and ending waypoint.

An example of enhancing air route network consists in offering a direct routing plan that apart from traditional ENR chart offers shortcuts to the original airways performing straighter and more effective routes. This type of airway is widely developed in the next section.

1.2.3. DCT

DCT or direct routing consists in offering a straighter way to cross airspaces than doing it with conventional routing. This concept started being developed to meet airspace users desire of performing more efficient routes, aiming to allow them to fly their preferred trajectories without the need to adhere to a predefined route structure. In the next figure (figure 1.2) is represented this preferred trajectory:

Figure 1.2 Most efficient route against conventional routes

These procedures could not have been possible before the introduction of RNAV systems in the aircraft. It is required to have RNAV instrumentation to perform a DCT because it allows DTCs main principle, the execution of routes involving unpublished waypoints, in between published points. Indeed, as RNAV was first introduced in 1998 [8], almost all current aircraft have this equipment enabling them to do DCTs.

Despite the fact that sometimes DCTs are done during departure or arrival procedures, commonly these are performed during cruise. This is because it is recommended to do them in the upper airspace where the chance of conflict is lower, although, there is not a minimum flight level to perform them.

It is becoming more and more frequent the use of these shortcuts. In order to regulate it, some countries have established DCTs networks in their airspaces. These networks allow to plan a DCT in the flightplan, however, there are lots of them that are not defined in the AIPs which are done without being planned. The pilots have two ways to obtain clearance to do unregistered DCTs: by requesting it to ATCOs or by own proposal of the ATCOs.

Finally it has to be differentiated between two types of this procedure: DCTs done within a unique airspace and DCTs that cross airspace borders. The second ones are less used due to the fact that it increase workload and require for coordination between ATCOs. This is one of the main reasons why only a few cross-border DCTs are published in the DCT networks, however, in the main analysis, it will be proved that they are quite frequently done and even with three countries involved.

1.3. EUROCONTROL

In terms of organization there are four stakeholders that cooperate between them to ensure that the air transportation within Europe complies the required levels of efficiency and safety: European Aviation Safety Agency (EASA), European commission (EC), European Civil Aviation Conference (ECAC) and

EUROCONTROL. As the aim of this project regards air navigation matters, the European Organisation for the Safety of Air Navigation (EUROCONTROL) is the key role player that has to be focused because its functions affect this issue.

EUROCONTROL is an intergovernmental organisation, founded in 1960, with 41 Member States whose activities include: managing the ATM network; handling billing across Europe; supporting the European Commission, EASA, and National Supervisory Authorities in their regulatory activities; and civil-military aviation coordination in Europe. The company also offers services in the areas of aeronautical information management; airspace management and organization; ATM training; communications, navigation and surveillance; economics and business cases; environmental impact on aviation; human performance in ATM; safety; simulations and statistics and forecasts [27].

In addition, it provides air traffic management (ATM) services to: civil and military airspace users, airports and national authorities and air navigation service providers (ANSPs). The ANSPs are crucial participants in the management of the European Airspace due to the reason continually explained.

1.3.1. Air Navigation Service Provider (ANSP)

An Air Navigation Service Provider by definition is any public or private entity providing air navigation services for general air traffic [28]. These are: Air Traffic Services (ATS), the Communication, Navigation and Surveillance Services (CNS), the Meteorological Services for Air Navigation (METEO), and the Aeronautical Information Services (AIS).

Since Europe has one of the most complex airspaces in the world due to the high amount of countries that belong to it, everyone with a different ANSP providing services for it and a different situation to take into account (financial, importance of its airspace, point of view regarding the future, etc.), it should exist a governor between them. That is why EUROCONTROL has an important role, it is to coordinate betweenthe different national ANSPs in terms of interconnection of airspace and standards of interoperability.

Moreover, EUROCONTROL has the mission to regulate the system for the recovery of the costs of air traffic management (ATM) services provided by the ANSPs. EUROCONTROL ensures transparency and efficiency of cost-recovery by means of a centralized office who is responsible for establishing, billing, collecting and disbursing the charges collected to the States [27].

1.3.2. The charging system

The centralized office previously mentioned is called Central Route Charges Office (CRCO). The charges that it bills and collect, using as currency the euro, constitute remuneration for the cost of: ATM provision (divided into air traffic services (ATS), air traffic flow management (ATFM) and airspace management (ASM)), communications facilities, navigation services, surveillance systems, search and rescue, aeronautical information, meteorological services, supervision and other costs.

The primary income of the charges comes from the ATS which can also be .divided in three different services: area control service, approach control service, and aerodrome control service. As the aim of this project is to enhance the en-route charges, it is only required the outlook of the area control service charges.

1.3.2.1. En-route charges

The route charges are the ones referring to the area control services, these are applied for each flight using an airspace, although there are some flights exempt from the payment charges, these cases are detailed in **annex A**.

The following equation shows how the en-route charges are calculated [9]:

$$R = \sum_n t_i * \left(d_i * \sqrt{\frac{Max.take-off\ weight}{50}} \right) \qquad (x)$$

The result is equal to the sum of the charges applied to all the airspaces overflown by the aircraft. Where Max. take-off weight, t_i and d_i are:

$Max.take-off\ weight$ is expressed in number of metric tons with one decimal, and has to be the one specified in the certificate of airworthiness, the flight manual or any other equivalent official document.

$t_i = unit\ rate\ of\ charge.$

The unit rate of charge which is different for each airspace and is determined every month, it consist of two parts: the unit rate, set by the ANSP, obtained by dividing the en-route facility forecast cost-base of the charging zone or airspace concerned for the reference year by the forecast number of flights controlled and the administrative unit rate, set by CRCO, aiming to recover the costs of collecting route charges. See annex B map and a table which give an overview of the difference between the unit rates of route charges.

$d_i = distance\ factor$

The distance factor is obtained by dividing by one hundred (100) the number of kilometres in the great circle distance (shortest distance between two points) between: the aerodrome of departure or the entry point and the aerodrome of destination of the exit point of the airspace. When this distance is computed one consideration is taken into account, for all flights departing or landing within an airspace belonging to the CRCO there is a deduction in direct route length by 20 kilometres. This is done to adjust the route length avoiding to include the length of Standard Instrumental Departures and Standard Terminal Arrival

Routes (STAR). The following figure (figure 1.3) gives an example of how is computed this distance:

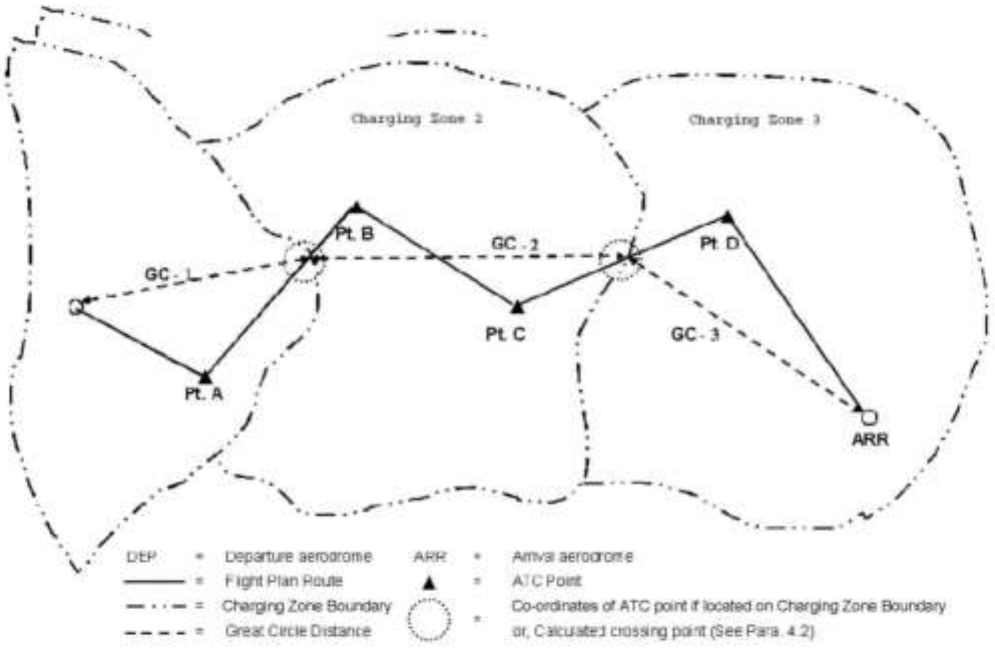

Figure 1.3 Example of distance calculation using the great circle distance principle [10]

The distance charged is always the one corresponding to the route described in the flight plan. This sentence has to be highlighted because is directly related with the aim of doing this project, it means that if a non-published changing border DCT is done the charges applied will not be different. These could be higher or lower, but if these DCTs were published the charges applied would be different. It is because when it is done a cross-border DCT the entry/exit point is changed with respect to the point determined in the flightplan, which refers to the published routing.

1.4. Future Airspace: Single European Sky

EUROCONTROL as a part of the SESAR Joint Undertaking is involved in the development of Single European Sky ATM research (SESAR) [29], a project that aims to modernize the European Airspace. It offers research, development, and validation services to the SESAR Joint Undertaking and moreover, as part of this programme, it provides air traffic control services for the Netherlands, Belgium, Luxembourg, and northern Germany with the Maastricht Upper Area Control Centre (MUAC). With this, it tries to give working example of how European cooperation, both at a civil and military level, can result in safety, capacity and efficiency benefits for all.

The project started in 2004 has three phases: a definition phase (2004–2008), a development phase (2008–2013) and a deployment phase (2014–2020). This ambitious program has the aim to reform the architecture of European airspace and its air traffic control to increase the overall efficiency and meet future capacity and safety needs.

In order to achieve this objective SESAR is providing solutions to different ambits of the air transportation, these are: enabling aviation infrastructure, optimised ATM network services, high performing airport operations and advanced air traffic services.

The understanding of two solutions is a needed background for a farther comprehension of the content of this document, the implementation of the functional airspace blocks (FABs) and the free routing airspace (FRA).

1.4.1. Functional Airspace block (FAB)

A Functional airspace block (FAB) is defined by the Single European Sky (SES) as follows:

“A FAB means an airspace block based on operational requirements and established regardless of State boundaries, where the provision of air navigation services and related functions are performance-driven and optimized with a view to introducing, in each functional airspace block, enhanced cooperation among air navigation service providers or, where appropriate, an integrated provider.”

The establishment of the FABs is a key mechanism for reducing airspace fragmentation because now a days the European airspace is still organised in a segregated way. Every time a plane enters the airspace of a Member State, it is serviced by a different air navigation service provider (ANSP) on the basis of different rules, operational requirements and charges applied for its use. It makes the introduction of the FABs completely necessary to accommodate the steadily growing traffic, as well as to maximize the airspace efficency by managing the traffic more dynamically [11].

In this purpose, the 67 current airspace blocks in Europe are wanted to be converted into only nine functional airspace blocks, those are showed in the following figure (figure 1.4):

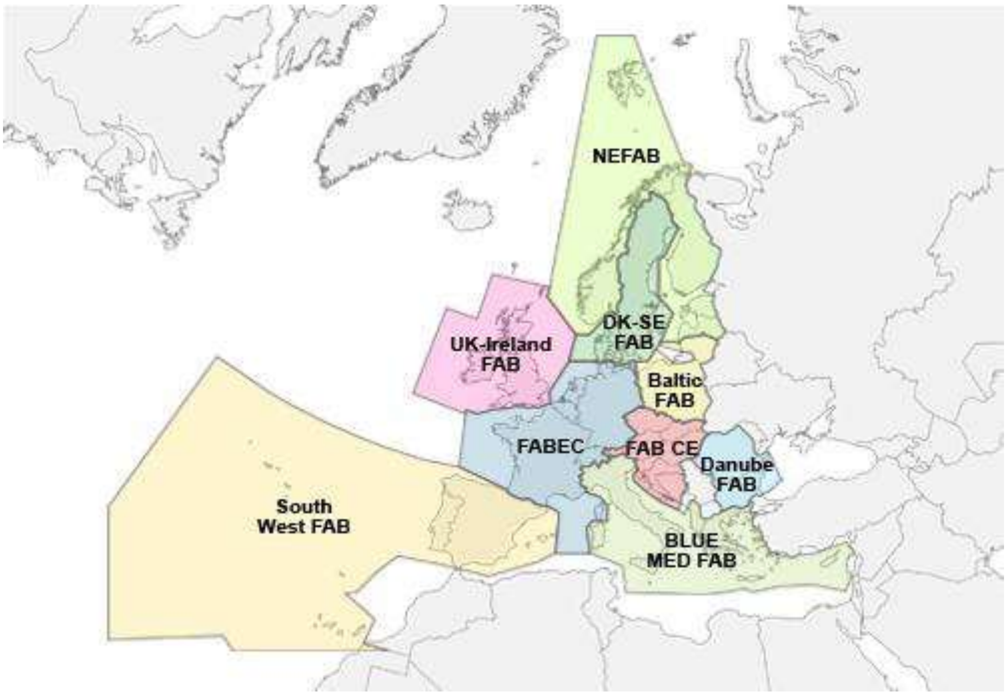

Figure 1.4 European FABs

1.4.2. Free Routing Airspace (FRA)

EUROCONTROL defines Free Routing Airspaces as [12]:

"A specified airspace within which users may freely plan a route between a defined entry point and a defined exit point, with the possibility to route via intermediate (published or unpublished) way points, without reference to the ATS route network, subject to airspace availability. Within this airspace, flights remain subject to air traffic control"

This concept is starting to be a reality in some European countries, however, it has a difficult implementation phase. Aiming to introduce the FRA, it has to be taken in consideration the complexity of the airspace because a full implementation of Free Route Airspace Operations could potentially have a detrimental effect on capacity. For this reason it is recommended a transitioning period between free route and fixed route operations, applying it only during a limited period of time, i.e. nights or weekends.

This staggered implementation can make easier its introduction and the assessment of future problems. However, if the application of a free routing airspace is not feasible it can be set a direct segments (DCT) plan offering high efficient routes within the airspace and ,if possible, doing cross-border DCTs coordinating ANS services. Indeed, a DCT plan also can be a previous phase of the FRA introduction. See **annex C** for the last update in the Free Route Airspace Implementation provided by EUROCONTROL

CHAPTER 2. NEST

2.1. Introduction

The tool used to perform the analysis of this project is the NEST (Network Strategic Tool). It is a processing application capable of running a broad range of complex analysis and optimisation functionalities. It is used by (EUROCONTROL) and airspace stakeholders for airspace structure design and development, for capacity planning and post operations analysis, for strategic traffic flow organization, for scenario preparation for fast and real-time simulations and for ad-hoc studies at the local and network level. [27]

In order to run Nest it is necessary to use datasets of European airspaces and route network, the traffic demand and traffic forecasts. All this data can be downloaded from the Demand Data Repository (DDR) in only one file, the AIRAC (Aeronautical Information Regulation and Control). However, this information is not open to everyone because it is needed a website subscription provided by EUROCONTROL at the OneSky Extranet [30].

An AIRAC (Aeronautical Information Regulation and Control) contains all the real required information to run NEST features: flights, airports, sectors, etc. These data are renewed every 28 days to ensure that all users of the tool receive new changes to existing information. These updates are done with the aim to obtain more reliable results by having more actual information when making simulations.

2.2. Interface

NEST offers an intuitive and user-friendly interface allowing the user to customize the scenario, navigate through it and run functions easily. The main interface has three differentiated main parts: data browser, map, and menus and toolbars.

- Data browser: Located in the left side, the data browser panel contains three tabs: airspace, network and traffic. Its purpose is to navigate through the data contained in the AIRAC allowing the selected data to be displayed on the map.

- Map: The map is used to display and edit selected data browser items and to visualize analysis results. It is fully customizable, allowing to change colours and line widths among other personalizing functions. Moreover, it can be zoomed in and out, be moved on every direction and be changed between 2D and 3D views, making easier its navigation.

- Menu and toolbar: On the top of the window there are the toolbar buttons which are a selection of the most frequently used functions. Indeed, all this quick accesses are also features that can be found in the menu groups, which are: file, edit, view, scenario, processing, analysis, transform, tools, map and help.

The next figure (figure 2.1) shows how the main interface of Nest is:

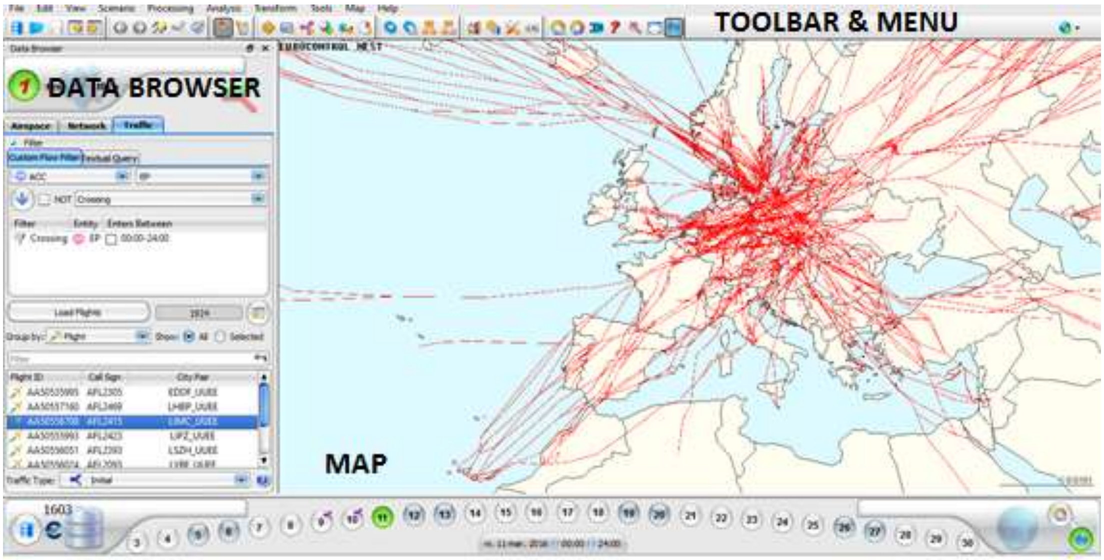

Figure 2.1 Nest interface

2.3. Functions used

NEST has a wide range of capabilities, however, only a few of them are used to develop the main part of this project (chapter 3), these functions are briefly explained in this section. For detailed information of all the features, NEST offers a help pdf [13].

2.3.1. Traffic data

Nest allows to extract information of the traffic selected in the data browser in a file. It can be done for one to as many flights as required, but, as for a determined traffic analysis not every flight is useful the data browser has filters. The selected filters are combined automatically using the AND operator and can be optionally negated using the NOT operator. The filtering entities include flight callsigns, aircraft, airlines, trajectory status, airports, set of airports, city pairs, navigation points, network segments, ACCs, etc. The following figure (figure 2.2) show these filters:

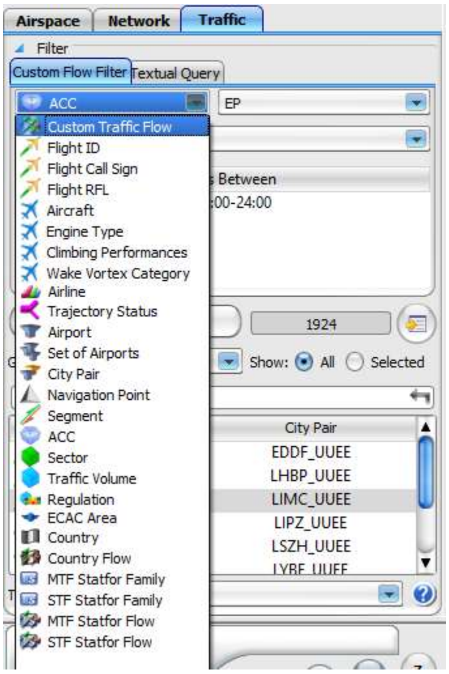

Figure 2.2 NEST data browser filters

Once selected the flights, by right clicking on them it is deployed a menu with some options (flight list, flight route, vertical profile, copy flight and delete flight). The option to extract the flight data is *flight list*, it opens a new window with a list of all selected flights. In the window it can be seen some information of each flight, moreover, it can be extracted all the flight information in different formats. The type of file required for analysis processes is a traffic file (*.so6), which has all the information regarding each flight (origin and destination airports, aircraft type, airline, route segments, latitude and longitude of the waypoints, etc.)

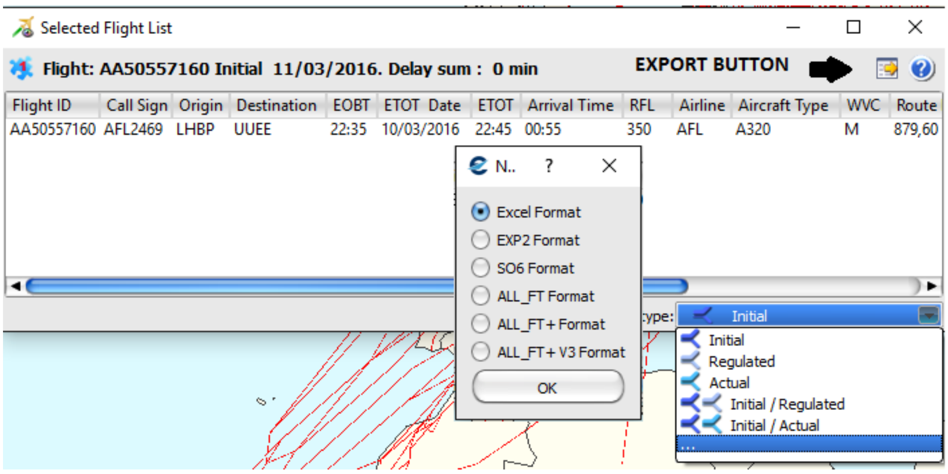

Figure 2.3 Flight list window

In the previous figure (figure 2.3) it is showed the mentioned window. An important fact when exporting this file is that it can only be done by one trajectory at the same time (initial, regulated or actual). The initial route is the one set in the original flightplan, the regulated also refers to the planned but after possible modifications done before flight due to restrictions, meteorology, etc. and the actual trajectory is the real flight performed by the aircraft.

2.3.2. Route charge

Route Charge is a specific module in the analysis menu that has been developed for the CRCO. It calculates for each flight the cost due to operate in the European airspace. It combines two inputs a traffic file (*.so6) and an associated intersection file (*.t5) to produce a route charge data file. The traffic file is obtained with the function mentioned above, regarding the intersection file it can be calculated with the Airspace/Traffic Intersection function explained in the next section (2.3.3).

The other inputs are the CRCO data: aircraft weights, unit rates and member states. NEST can take this information directly from the AIRAC so is not a must to input these files.

The outputs can be extracted with different formats (*.xls,*.cost, *_crco.t5 and *_crco.so6). It has been chosen the type of file (*xls), that can be used with Excel, because it allows to analyse the data and to compare the charges between the initial and actual trajectory. This excel report shows the route charges: per country, per flight and per flight&country. The following figure (figure 2.4) shows this module window:

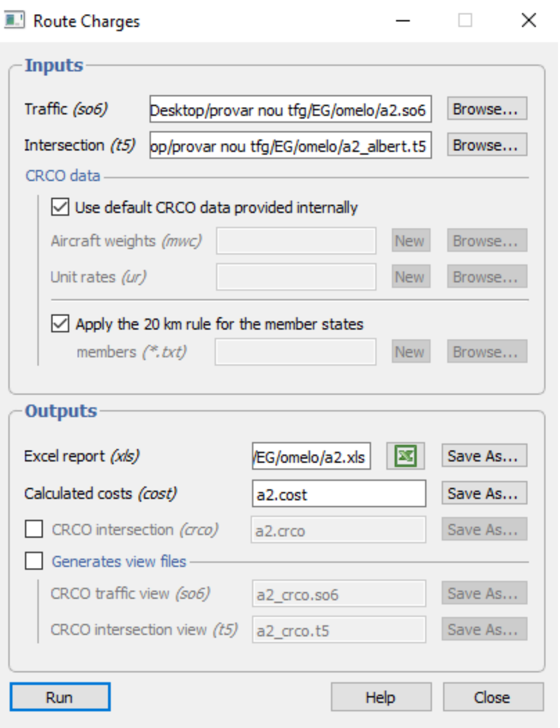

Figure 2.4. Route charges module

2.3.3. Airspace/Traffic Intersection

This feature of the processing menu computes 4D intersections of traffic with airspace volumes. The necessary inputs are a traffic file (*so6) and two airspace files (*.are) and (*.sls). For the specific case of the route charges NEST provides the files corresponding to the charges areas in the required format (CRCO_ChargeAreas.are and CRCO_ChargeAreas.sls)

The output file (*.t5) obtained contains the entry point and the exit point expressed with coordinates, flight level and time. Other fields are also processed like duration and distance within the airspace volumes. In the next figure (figure 2.5) it is shown the window of this feature:

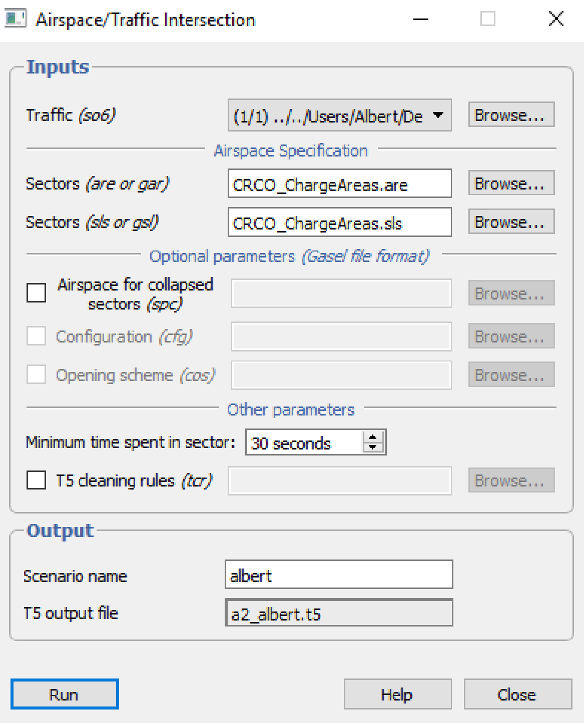

Figure 2.5 Airspace/Traffic Intersection module

2.3.4. Assignment

The purpose of this function of the processing tools menu is to find routes on a given network for a given traffic demand, the routes found are the shortest ones. Using this module, NEST is capable to assign a route to all the city pairs that has the traffic demand file.

The necessary inputs for this process are: a traffic demand file (*.exp or *.exp2) which contains the aircraft information, time and destination of departure and landing airport; a description of the route network, which is a set of different files and an airport coordinates file (*.arp). In addition, two more optional files can be added: area definitions file (*soa) and route length extension exception file

(*.rlex). It has to be born in mind that the optional inputs overload the program and it usually crashes when processing a high amount of traffic demand, so they have to be omitted when using big traffic files.

While the outputs obtained are: a profile file (*.zin), missing flights file (*exp2) containing the flights not assigned or badly assigned and a log file (*log) with warnings for inconsistencies in the input files. Moreover, there are also two optional files: a loaded network file (*.ase) which contains the number of flights on each route segment and a 2D traffic file (*so6). Despite the fact that the 2D traffic file is optional, it is the best way to see if the assignment has been done correctly. It only has to be introduced in the AIRAC traffic and afterwards display the flights on the map. The following figure (figure 2.6) show the window of this module with optional inputs disabled and the required 2D traffic output enabled:

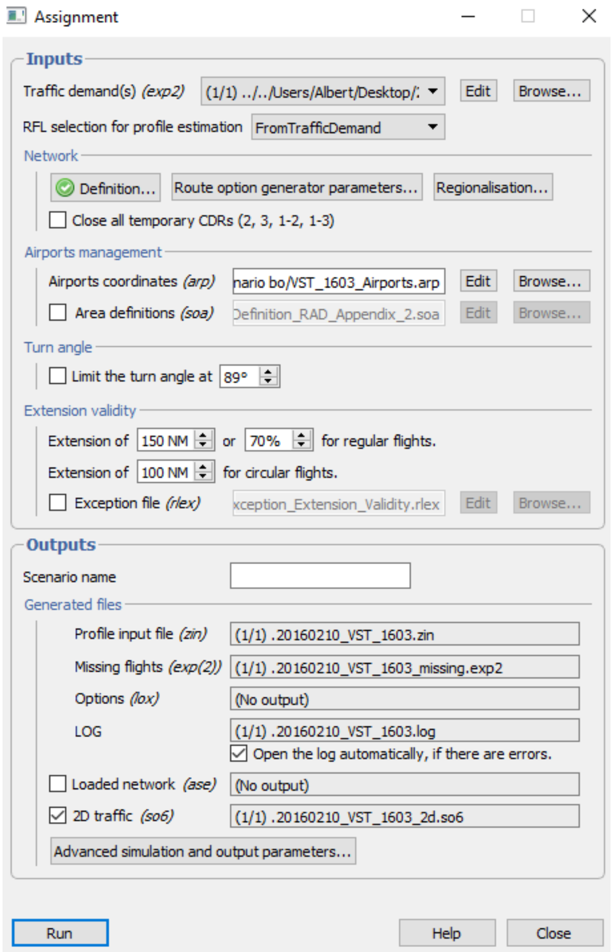

Figure 2.6 Assignment module

CHAPTER 3. DCT ANALISYS AND PROPOSAL

3.1. Introduction

In order to propose DCTs that change the entry points of airspaces, it is necessary to study them. The method followed to do it finds DCTs comparing the initial and actual flight by means of displayed flights in NEST, the traffic files used in this project correspond to the AIRAC of February and March of 2016. Once found a feasible proposal, it has to be checked if there already exist a published DCT, which is not used in the flightplan of, contrasting the networks and other similar flights. If the DCT is not registered, the computation of charges is done taking in account some considerations explained below:

- The calculation of the charges is done for all the airspaces affected by the DTCs, this method tries to give a more reliable result of the savings when applying a DCT. The reason of this consideration is because a new proposal of entry points for a DCT can be not optimum in terms of ANSP savings, given that the charges per NM are different in every country. Using that, the cost of all the DCT is taken in account, not only the airspace mainly affected, being able to discard non profitable changes of airspace entry points.

- The number of flights for the study of the applied charges in the planed and the performed route is 50 for each DTC, this sample of flights is heterogeneous because the airspace is not flown by only one type of aircraft, obtaining with this a general view of the en-route charges and savings. The calculated values are: total and average charges, and the economical savings obtained if the proposed DCT would be set in the AIP.

3.2. Slovakian Airspace

The airspace of this country located in central Europe is formed by one flight information region, the Bratislava FIR (LZBB). The M. R. Štefánik Airport (LZIB) located in Bratislava is the most important of the country with 1.5M pax. in 2015 [31] but as the Vienna International Airport (LOWW) is only 50km far from Bratislava, the Slovakian airspace is highly influenced by it. Daily the LZ ACC controlls an average of 1080 flights, the number of flights overflying Slovakia is increasing every year and this amount can be doubled during the summer season.

Slovakian Air Route Traffic Control Center has to deal with a small surface (49 km2). However, as it has five diferent airspace boundaries (EPWW, LKAA, LOVV, LHCC and UKLV), this implies a high cooperation with the ANSPs of the bordering countries to increase the cross-border operations coordination and the efficiency of its airspace. Despite the fact that these countries have implemented some mesures to incease they capacity (DCT segments or FRA

(24h or during night)), the ANSP of Slovakia (*LPS SR*) [14] hasn't introduced any of them (figure 3.1).

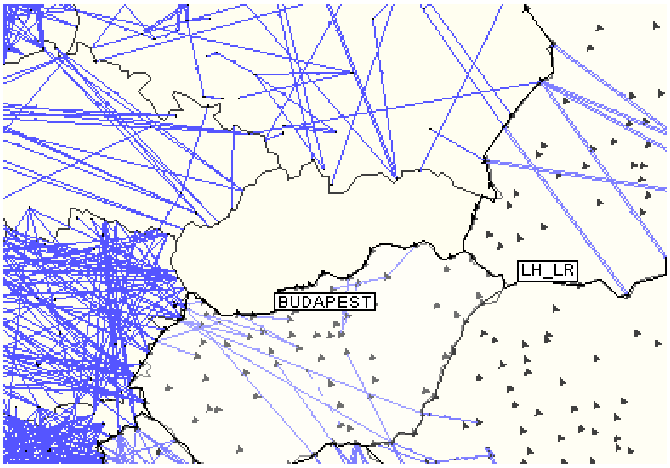

Figure 3.1 Slovakian and bordering countries DCT and FRA network

Nevertheless, in order to further enhance safety and efficiency of air traffic, the structure of routes is being optimized continuously. The air traffic controller officers (ATCOs) are frequently giving DCTs in two different cases of routes:

- Flights coming/going form Austria to Poland.
- Flights coming/going form Poland to Hunagry.

3.2.1. First case

These type of flights which are coming or going from South Europe (Italy; Spain or France) to North Europe (Russia, Poland or Baltics) cross Slovakian airspace borders at ABLOM (border with Austria) and exit at SUPAK or MEBAN(border with Poland).

The daily average of flights which follow this route is 24, where at least 90% of them are given a DCT usually changing the border entry point of Poland but not the one at the Austrian border, because form ABLOM there is an existing DCT segment to ABTAN. However, sometimes a more efficient DCT is performed where both points are changed, following a route from ABTAN or MALUG (Austria) to PUBOK, BIGLU or OBOSO (Poland). The following figure (figure 3.2) shows these routes and some DCTs used:

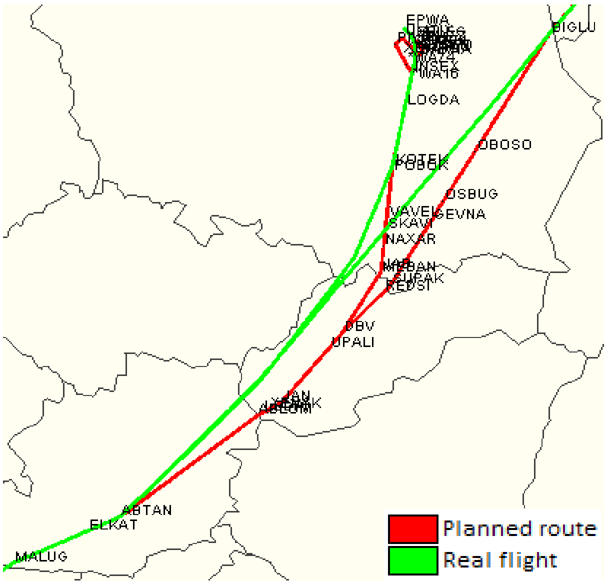

Figure 3.2 First case Slovakian airspace routes analysed and most optimum DCTs used

3.2.1.1. ANSP costs

Table 3.1 First DCT case Slovakian airspace charges analysis

	Total (€)	Mean per Flight (€)
Charges applicable to the planned flight	35018,63	714,66
Charges applicable to the performed flight	34119,68	696,32
Charges Savings	898,951	18,34

3.2.1.2. Proposal

Regarding this case, the most optimum solution would be the creation of two new entry points, one on the Polish border (SLPO1) and another one on the Austrian (SLAU1). These points should be connected by a DTC segment in the Slovakian airspace, moreover, segments linking the existing points in the adjoining countries to the new ones should be designed in order to make the flight plans more efficient and avoid DCT request to ATCOs when overflying them.

The following figure (figure 3.3) show the new proposal of directs for this case, the solution offers different DCT segments trying to fit with as many routes as possible.

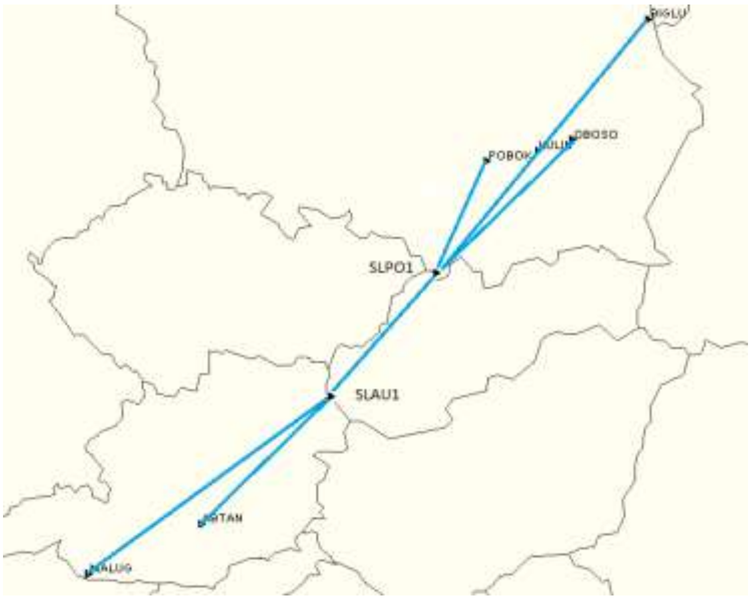

Figure 3.3 First case Slovakian airspace DCT proposal

As can be seen in the picture the new Austrian bordering point will connect with MALUG and ABTAN, and the one in the Polish border with POBOK, OBOSO and BIGLU (this route has an intermediate NAV point (LULIN) to fulfill the ICAO rules described in section 1.2.2.2

3.2.2. Second Case

These flights are mostly departing or arriving from Russia to Greece and the countries next to the Black sea (Turkey, Rumania, Bulgaria and Moldavia). They avoid crossing Ukraine overflying Slovakia, these operations are performing this route due to the ban of Ukraine to the Russian airlines. The planed route use the entry points PODAN (Polish border) and KENIN (Hungarian border) as shows next figure (figure 3.4).

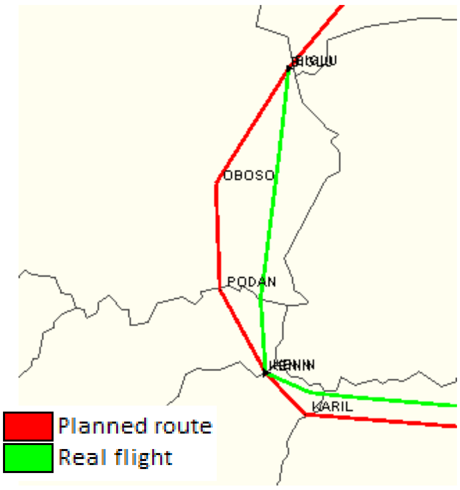

Figure 3.4 Second case Slovakian airspace route analysed

This segment is planned by an average of 15 flights every day, where more than an 80% of them are given a DCT that goes straight from the entry point BIGLU in the Polish airspace to KENIN avoiding with this do a bend as the previous figure (figure 3.4) shows.

3.2.2.1. ANSP costs

Table 3.2 Second DCT case Slovakian airspace charges analysis

	Total (€)	Mean per Flight (€)
Charges applicable to the planned flight	9729,94	194,59
Charges applicable to the performed flight	8749,20	174,98
Charges Savings	980,73	19,61

3.2.2.2. Proposal

In this scenario the solution is to set a new entry point on the Polish border of the Slovakian airspace (SLPO2). In addition, define a DTC segment from KENIN to this new point and another one connecting this new air-segment with BIGLU. The following figure (figure 3.5) is the result of applying this suggestion:

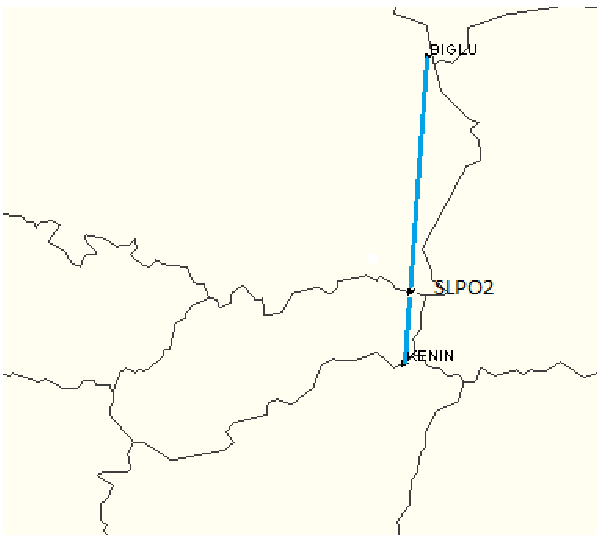

Figure 3.5 Second case Slovakian airspace DCT proposal

3.3. Polish Airspace

The airspace of Poland is formed by one flight information region, the Warszawa FIR (EPWW), it consists of the airspace over the land of the country and certain airspace over the Baltic Sea with total geographic area of 334000km2 [16]. The Warsaw Chopin Airport (EPWA) is the busiest airport of the country with 11.2M pax. on 2015 [32]. The aircraft overflying this country are mainly affected by a huge militar activity and its location, it is on the way of all the flights of the main Europe airports (EHAM, LFPG, EGKK, EGLL, EBBR, EDDF, EDDM) to Asia and East Europe.

The EPWW FIR has terrain borders to the East, South and West, where it borders on the Vilnius, Minsk, L'vov, Bratislava, Praha and Berlin FIRs. To the North it covers a part of the Baltic Sea, it shares boundaries with the Malmö and Kaliningrad FIRs [15]. (figure 3.6)

Figure 3.6 Polish airspace and bordering countries

The ANS of the EZ ACC are provided by the *Polish Air Navigation Services Agency* (PANSA), it has to deal with an average of 1850 flights every day. The forecast predicts an increase in the operations of a 3.7% during the following years[16]. As a part of the SESAR programe the ANSP has implemented some measures to reach the FRA (Baltic FAB) this modifications are focused in increase the airspace capacity among others. Now a days Poland has applied a DCT plan that has slightly different offer between day and night or weekend (figure 3.7), but as the daily operations show in NEST, it is not fully opreational. The majority of the flightplans are not using these predetermined DTC segements, however, the ATCOs are frequently giving other non-published DCTs. The most common routes where non-published DCTs are given in Poland are:

- Flights going form Germany to Lituania.
- Flights coming/going form East Europe to Czech Republic.

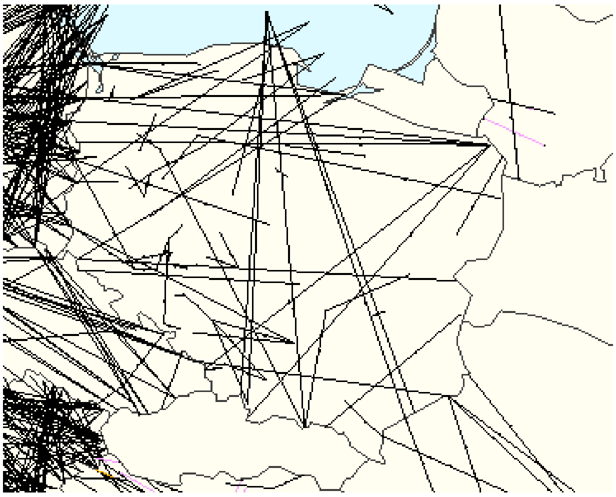

Figure 3.7 Polish daily DCT network

3.3.1. First case

These type of flights which are going from England, Belgium or the Netherlands to East Europe or Asia cross the Polish airspace borders at a wide range of NAV points on the border with Germany. They are headed to the entry points BOSKU or VABER on the Polish border with Lithuania. This DCT has to be evaluated in consideration of what the flight does in the German airspace because usually it starts doing another unregistered DTC from a segment that intersects with a NAV point. The next figure (figure 3.8) has some examples of it:

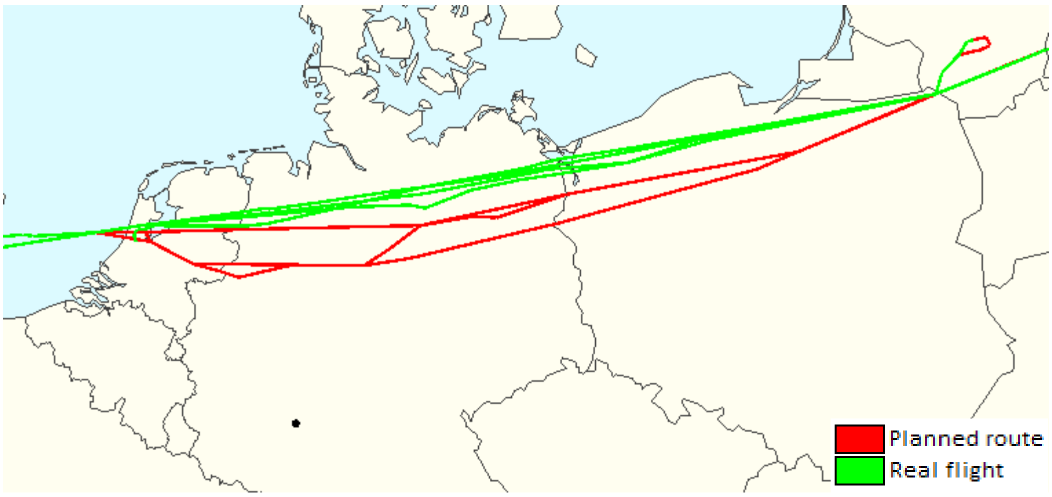

Figure 3.8 First case Polish airspace routes analysed

The daily average of flights which follow this route is 70, where at least 65% of them are given a DCT. When this kind of DCT is performed the entry point of Lithuania remains used, but not the one at the German border, because it depends on if the landing airport is more northern or southern.

3.3.1.1. ANSP costs

Table 3.3 First DCT case Polish airspace charges analysis

	Total (€)	Mean per flight (€)
Charges applicable to the planned flight	59057,08	1181,14
Charges applicable to the performed flight	57295,31	1145,90
Charges Savings	1761,77	35,24

3.3.1.2. Proposal

For this case at least three new entry points should be created, one on the Polish border with Germany (POGE1) and two on the German border with Netherlands (PONE1 and PONE2). These points should be connected by DTC segments. Moreover, as there are segments longer than what the ICAO establishes as maximum distance between waypoints (section 1.2.2.2), some intermediate NAV points have to be set. The DCTs will link the two entry points on the Netherlands with Lithuania, whose entry point BOKSU will remain.

Figure 3.9 First case Polish airspace DCT proposal

As can be seen in the previous figure (figure 3.9) the Lithuanian bordering point (BOKSU) will connect with the new entry point on the German border with Poland (POGE1) or a similar existing one, PESEL. The DTC will cross RATOR as an intermediate NAV point on the Polish airspace. Finally, in the German airspace, POGE1 will connect with two entry points on the Netherlands border (PONE1 and PONE2); and these two new segments will also have intermediate

NAV points, which in this case will be TEGAD and KEGAB depending on the starting location.

3.3.2. Second Case

The flights analyzed in this example overfly Poland going/coming from South Europe flying through Czech Republic. There are two routes where the DCTs are applied, they are differentiated by if they land or depart in Munich Airport (EDDM) or not. The ones that operate in that airport use two entry points depending on if they are arriving or departing: LAGAR for departures and TOMTI for landings, both points on the Polish border with Czech Republic. The other routes use only LAGAR as entry point. .

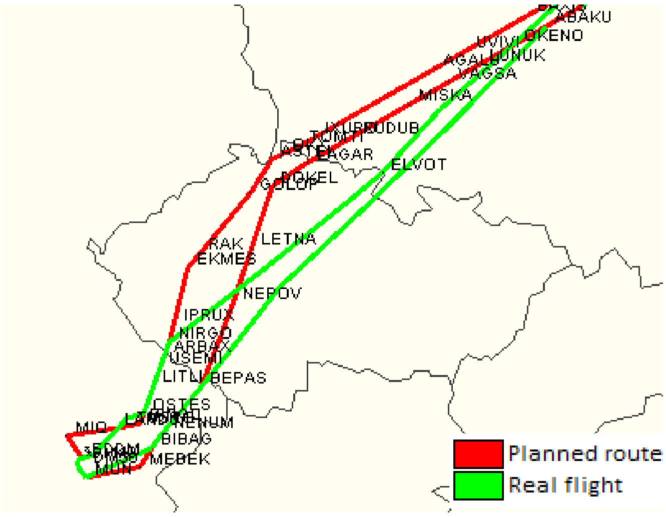

Figure 3.10 Second case Polish airspace routes analysed

As shown in the previous figure (figure 3.10) the other ends of the DCT are: BEPAS which is an entry point on the Czech border with Germany and in the case of the flights landing in Munich NIRGO because is the beginning of the STAR procedure. The DTCs tend to go from Poland to one of these points without entering to the Czech airspace by LAGAR or TOMTI.

Depending on the route DCTs are performed starting in POLON which is a NAV point within Poland or RUDKA an entry point of the Polish Airspace in Belarus. These routes have a frequency of around 75 flights every day, where more than a 95% are trimmed by using DCTs.

3.3.2.1. ANSP costs

Table 3.4 Second DCT case Polish airspace charges analysis

	Total (€)	Mean per flight (€)
Charges applicable to the planned flight	18143,46	362,86
Charges applicable to the performed flight	17746,19	354,92
Charges Savings	397,27	7,94

3.3.2.2. Proposal

Despite the fact that the charges analysis shows that by proposing the introduction of these DCTs the ANSP savings obtained will not be huge, it is still a suitable application. That is because a part from the fuel, time and emissions reduction, this route has a considerable frequency, 75 flights per day as mentioned before, which would mean a saving of around 75x7.94€≈600 € daily. So to fulfill all the similar routes regarding this case some points linked by DCT segments should be added in the Polish AIP.

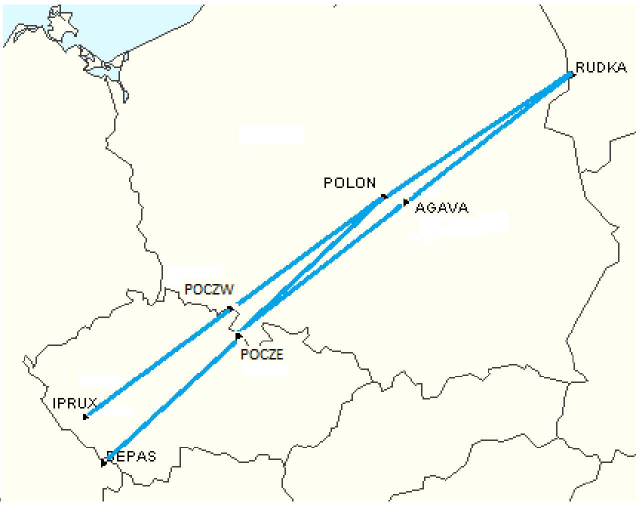

Figure 3.11 Second case Polish airspace DCT proposal

As shown in the previous figure (figure 3.11), In order to carry out this recommendation two new entry points have to be set on the Polish border with Czech Republic. In the Czech airspace the new entry point which is further west (POCZW) is going to be linked with IPRUX and the other one (POCZE) with BEPAS. Regarding the Polish airspace both points are going to be connected with air-segments with POLON and RUDKA, and the DCT that links RUDKA with the more eastern entry point is going to have an intermediate NAV point that already exists: AGAVA.

3.4. German Airspace

This airspace is divided in two flight information regions: Rhein FIR (EDUU) and Hannover FIR (EDVV). However, in order to understand its complexity, its contigous countries have to be taken in account. It has common borders with Poland (EP), Czeck Republik (LK), Austria (LO), Switzerland (LS), Denmark (EK) France (LF),Belgium (EB) and the Netherlands (EH).(figure 3.12)

From these countries, have to be highlighted the northern ones due to its influence on the German airspace. The Netherlands and Belgium, because with a part of Germany they form the Maastricht airspace (MUAC), which is known by the implementation of a high developed DCT plan and the cross-border cooperation between the involved countries in order to manage one of the most complex airspace structures in the world where the traffic flow is up to more than 5000 aircraft a day. And on the other hand, Denmark because its ANSP has already implemented the free routing in its airspace increasing the coordination difficulites with its adjoining countries.

Another key factor that repercute in the German airspace is the proximity to some of the busiest airports in europe. A lot of operations of the two airports of London (Gatwick (EGKK) and Heathrow (EGLL)), Amsterdam Schipool airport (EHAM) and Paris Charles de Gaulle Airport (LFPG) enter in Germany. Moreover, this country have four aiports with over 20 million passangers: Frankfurt, Munich, Düsseldorf and Berlin Tegel.

Figure 3.12 German airspace

All this factors implied that the German ANSP, *Deutsche Flugsicherung* (DFS), had to provide services to more than 3 million IFR flights during 2015 [17]. It supposed a rose in 1.6% points with respect to the previous year. As other countries in Europe, Germany is involved in the SESAR programme, it has implemented a DCT plan to enhance its airspace. This plan offers a large number of DCT segments which is considerably increased during nights and weekends, besides it is connected with the DCTs of the MUAC. In the following figure (figure 3.13) is represented this DTC airspace .

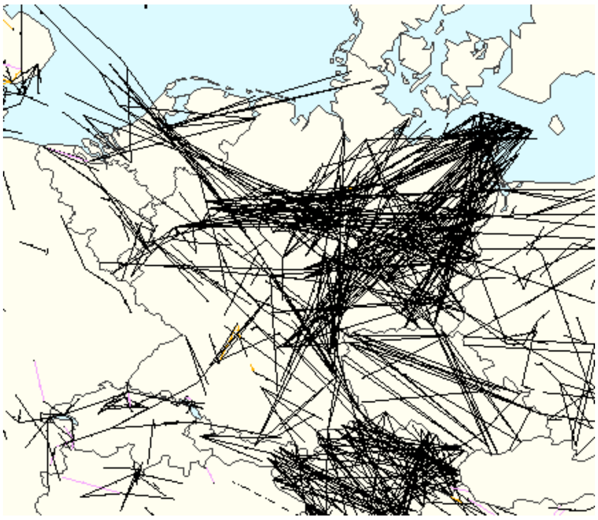

Figure 3.13 German daily DCT network

Despite the huge amount of DCTs proposed by the ANSP, some flights perform unregistered DCTs when overflying Germany. The implemantation of the following cases would help to improve the high developed DCT plan of Germany:

- Flights going form the South-East of Europe to the English airpots.
- Flights going form EHAM, North England or North America to the South East of Europe and Middle East.

3.4.1. First case

The flights which cover these routes enter at the German airspace by the Czech or Austrian border using the entry points VARIK and PASAU respectively and go to England arriving to a common NAV point once overflown the Netherlands, which is usually GORLO. When crossing to The Netherlands they use the entry points RELBI or GOMIS if coming from the Czech Republic or XULET if doing it from Austria. These flights perform a non-optimum route going to the north of Germany to afterwards fly south before entering to the Netherlands.

Figure 3.14 First case German airspace routes analysed

The previous figure (figure 3.14) shows the routes mentioned before and how these are trimmed by doing DCTs. These routes perform a straight line between NAV points in the German airspace and REFSO or GORLO avoiding doing this kind of triangle while crossing it. The daily average, considering the addition of both routes, is of 27 flights, where usually all of them perform a DTC.

3.4.1.1. ANSP costs

Table 3.5 First DCT case German airspace charges analysis

	Total (€)	Mean per flight (€)
Charges applicable to the planned flight	50101,79	1002,03
Charges applicable to the performed flight	49468,47	989,36
Charges Savings	633,31	12,66

3.4.1.2. Proposal

In this case to provide a shorter route for both cases two DCTs have to be established. There is no need to create new entry points at any border because there are some that fulfill the requirements of the new DCTs. The existing points are: XULET and DIBIR on the border of the Netherlands with the German airspace, PASAU on the Austrian and VARIK on the Czech. One DCT will link VARIK with XULET and the other one PASAU with DIBIR, the two with common ending at GORLO. Moreover according to the rule described in section 1.2.2.2, both segments will have intermediate NAV points as reference, EDEGA and RASPU respectively. This proposal is represented in the next figure (figure 3.15):

Figure 3.15 First case German airspace DCT proposal

3.4.2. Second case

These routes are used by the aircraft going from Germany to Czech Republic heading to the South-East. In order to exit the German airspace, the flights use the entry point OMELO to cross the border, once arrived to KOPIT (Czech NAV point), some flights turn left and others keep going straight depending on its destination. The airways planned perform a kind of bend that can be skipped by using a DCT. As farther from OMELO this DTC is executed, a more optimum route is achieved because the final flight is straighter.

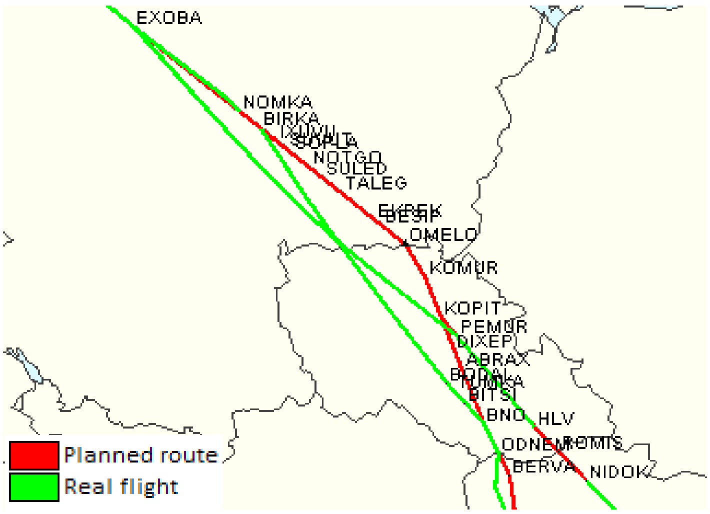

Figure 3.16 Second case German airspace route analysed

The previous figure (figure 3.16) shows the routes passing through OMELO and two of the most efficient DCTs applied. The route that have to turn start the DCT at EXOBA ending at KOPIT while the other begin at BRIKA to end at BTO.

About 65 flights every day operate it where usually a half of them are shorten with any kind of DCT.

3.4.2.1. ANSP costs

Table 3.6 Second DCT Case German airspace charges analysis

	Total (€)	Mean per flight (€)
Charges applicable to the planned flight	57123,41	1142,46
Charges applicable to the performed flight	55035,43	1100,70
Charges Savings	2087,98	41,75

3.4.2.2. Proposal

The introduction of two DCTs would offer an optimization when performing the routes regarding this scenario. However, it is only needed to propose one new entry point on the Czech border (GECZ1) because an existing one is useful to determine one of the DCTs, GAVLI. This point will be on the way of the DCT from NOMKA to BNO, while the new one will be used to define the other one which will go from EXOBA to KOPIT. This last DCT has to overfly an intermediate NAV point in the German airspace due to its length, this point is GERDO which actually also could be a defining point of the other DCT but it is not required. This proposal is represented in the next figure (figure 3.17):

Figure 3.17 Second case German airspace DCT proposal

3.5. Swiss Airspace

The airspace of this country is formed by only one flight information region, the Switzerland FIR (LSAS). Its airspace has a high complexity because given its location in the core area of Europe, Switzerland has significant demands from civil traffic overflying it, moreover, this amount of traffic has to be coordinated with abundant militar operations in a small size airspace. In addition, it has two international airports, Geneva Airport (LSGG) and Zürich Airport (LSZH), with 15.1 and 26.2 million passengers in 2015 respectively [33][34].

As can be seen in the next figure (figure 3.18) the LS ACC has to deal with four adjoining airspace areas: Germany, Austria, France and Italy.

Figure 3.18 Swiss airspace

The ANSP of the LS ACC is *Skyguide*, it handled an average of 3 225 flights a day in 2015 [18] with an increase of a 1.8% in its operations with respect to 2014, the forecast predicts a continous growth in the following years . The Swiss airspace has joined the SESAR programe, it is going to be part of the FABEC South East. So in this purpose Switzerland has implemented diverse DTC plans (daily, night and weekend) as show the following figure (figure 3.19).

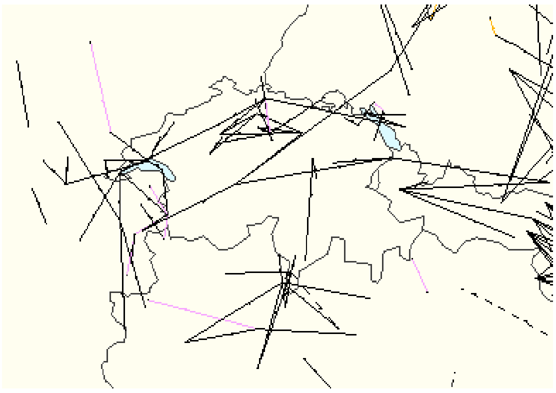

Figure 3.19 Swiss daily DCT network

However, with the help of the NEST tool, it can be seen that there are some cases of performed DCTs which are not established in these networks, those are:

- Flights going form France or England to Italy.
- Flights going form France or England to Middle East or Italy.
- Flights going form Germany or East Europe to North Spain or South France.

3.5.1. First case

These type of routes enter in Switzerland coming from France but they do it after entering in the German airspace at BEGAR to finally cross to Switzerland using the entry point *4756. One crossed Switzerland they enter in the Italian airspace at ODINA. Nevertheless, it is very frequent the use of a DCT. When performing it the flights go straight from France until ODINA without entering in the German airspace.

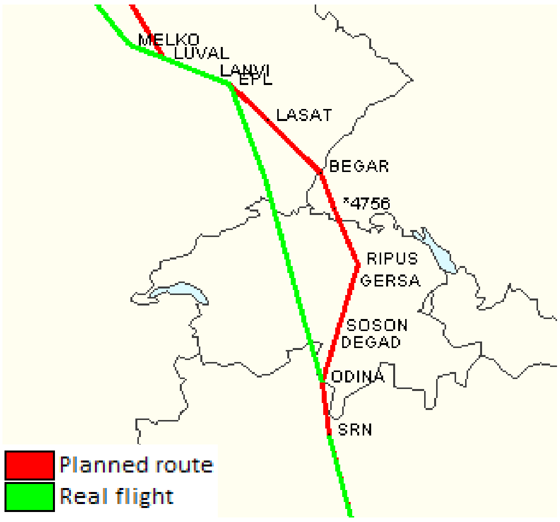

Figure 3.20 First case Swiss airspace route analysed

Regarding all the similar DCTs, the starting NAV points which enable the most direct way are LANVI and LUVAL as can be seen in the previous figure (figure 3.20).This route is performed for an average of 37 flights every day, where at least 85% of them trim it by using a DCT segment.

3.5.1.1. ANSP costs

Table 3.7 First DCT Case Swiss airspace charges analysis

	Total (€)	Mean per flight (€)
Charges applicable to the planned flight	36270,32	725,40
Charges applicable to the performed flight	34361,53	687,23
Charges Savings	1908,782	38,17

3.5.1.2. Proposal

The conditions of this DCT makes it generate lots of savings for such a short segment, as exemplify the calculations in the previous table (Table 3.7). That is because, apart from the obvious savings of flying less NM, it avoids entering into Germany whose airspace is one of the most expensive ones in the European region. The suggestion for this case lies in connecting LANVI with ODINA by means of a direct, this solution is the one that covers almost all the amount of routes without introducing lots of new points in the airspaces of Switzerland and France.

Figure 3.21 First case Swiss airspace DCT proposal

As can be noticed in the previous figure (figure 3.21), there is no need of creating a new entry point in the Swiss border with France because it already exist one that can be used, ABARI. So the application of this proposal only requires the introduction of two segments, one linking LANVI with ABARI and another ABARI with ODINA. However, there is one thing to consider, the air-segment between ABARI and ODINA exits and enters in the Swiss airspace during its course. This could be solved with two entry points more, but it would not be practical. Therefore, the solution resides in the optimization of the cross-border operations by doing the airspace transfer once overflown ODINA.

3.5.2. Second case

The use of this route has some similarities with the one analyzed above, it goes from France to Italy overflying Switzerland, the DCT applied does not enter in the German airspace and that LANVI is one of the NAV points of the flightplan. Nonetheless, as this route goes to more Eastern locations than the previous one, the airways used once entered in Switzerland are quite different. One of the endings of it is LUVAL or LANVI and crosses to the German airspace at BEGAR as before, but differently, it enters to Italy at the entry point RESIA. The following figure (figure 3.22) show an example of the route and the real flight using a DCT:

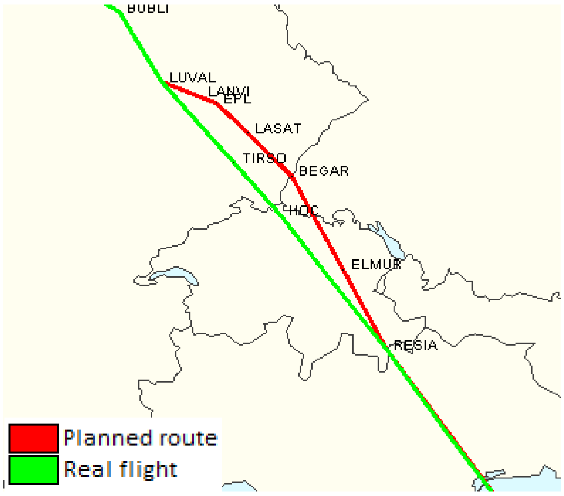

Figure 3.22 Second case Swiss airspace route analysed

When doing the mentioned DCT, the flight performs a straight line between LUVAL and RESIA avoiding entering in Germany. This route, as the preceding one, is planned by an important amount of flights, having a daily average over 35 flights. Even though the DCT shorten in some NM the original flightplans, the use of it is not widely extended, only around a 20% execute a DCT.

3.5.2.1. ANSP costs

Table 3.8 Second DCT Case Swiss airspace charges analysis

	Total (€)	Mean per flight (€)
Charges applicable to the planned flight	50022,73	1000,44
Charges applicable to the performed flight	49407,67	988,15
Charges Savings	614,31	12,28

3.5.2.2. Proposal

In contrast with the last one, this DCT is longer but it has less savings in the ANSP charges that is because in this scenario the amount of NM trimmed is considerably minor. The new air-segment that should be implemented to introduce this DCT in the AIP has to link LUVAL with RESIA straightly, moreover, a new entry point has to be set in the Swiss border with France (SWFR1) dividing the DCT in two segments as shows the next figure (figure 3.23).

Figure 3.23 Second case Swiss airspace DCT proposal

3.5.3. Third case

The route regarding this case is mostly used by the airplanes operating from Germany to the Spanish airports bathed by the Mediterranean Sea. The flights enter in the Swiss airspace coming from Germany usually by the entry point RINLI, although other entry points are also used, aircraft overfly Switzerland and cross to France exiting at MILPA. This route draws something similar to an inverse "L", although in most of the cases this is skipped by using a DCT. The following figure (figure 3.24) gives an example of it

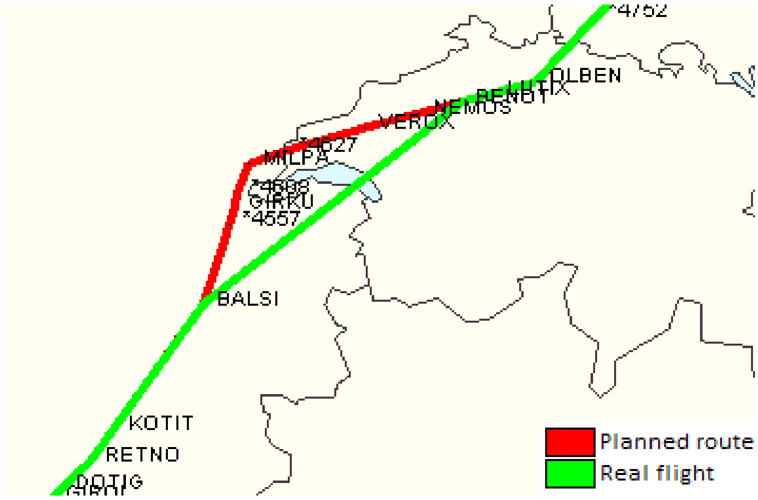

Figure 3.24 Third case Swiss airspace route analysed

As can be seen this DCT avoids turning with a reasonably closed angle once overflown the entry point MILPA. The different DCTs performed always go to BALSI starting its course at VEROX, NEMOS or somewhere in between these two NAV points. The daily average is more than 35 flights a day, but it can be much higher in summer because lots of German tourists visit Spain during this season. Referring to the rate of DCTs applied when flying this route, more than a 92% of the cases trim it.

3.5.3.1. ANSP costs

Table 3.9 Third DCT Case Swiss airspace charges analysis

	Total (€)	Mean per flight (€)
Charges applicable to the planned flight	34111,58	682,23
Charges applicable to the performed flight	32730,02	654,60
Charges Savings	1381,56	27,63

3.5.3.2. Proposal

The introduction of an air-segment joining BALSI with NEMOS or VEMOS added to the definition of a new entry point in the border of the Swiss airspace with France (SWFR2) which would be a reference when exiting Switzerland, would be the way to implement this DCT. Indeed, the most optimum DCT, which is the one represented in the following figure (figure 3.25), would go from NEMOS to BALSI because offers a straighter and longer segment.

Figure 3.25 Third case Swiss airspace DCT proposal

3.6. Italian Airspace

Italy has an airspace composed by three flight information regions: Rome FIR (LIRR), Brindisi FIR (LIBB) and Milano FIR (LIMM). These three regions constitute the Italian airspace, which covers a wide area formed by the Italian

Peninsula, Sicily, Sardinia and a part of the Mediterranean Sea (figure 3.2). The most important airport is Rome Leonardo da Vinci-Fiumicino (LIRF) with 38.5M pax.in 2015 [35] but it also has to be taken in account Milan Malpensa airport (LIMC) with more than 18.8M pax [36]. Apart from its airports with a significant number of passengers, Italy has an important strategic position in terms of aviation due to its location in the middle of the Mediterranean. All these considerations affect to increase the number of operations controlled by its ACC which is significantly high, 1.7M of en-route flights in 2015.

Figure 3.26 Italian airspace

The ANSP of the LI ACC is a public limited company called *Ente Nazionale per l'Assistenza al Volo* (ENAV). Despite the fact that in 2015 the number of en-route operations decresed in a 1.7%, the forecast predicts an increase in the operations during the following years[19]. ENAV is also part of the SESAR programe and specifically is going to be part of the Blue Med FAB. As the majority of the other European countries, Italy, has introduced some innovations to its ANS, however, on the topic of flightplan efficency as DCT or FRA these modifications are not enough developed. The airspace of Italy has different DCT configurations: the night and weekend ones that has a higher number of DCTs and the 24H Week that does not reach 20 DCT segments (figure 3.27). Nevertheless, during the day operatavie some non-published DCTs are given by the ATCOs, those are the following ones:

- Flights going form Spain to Italy.

- Flights coming/going form Germany to Italy trough Austria.

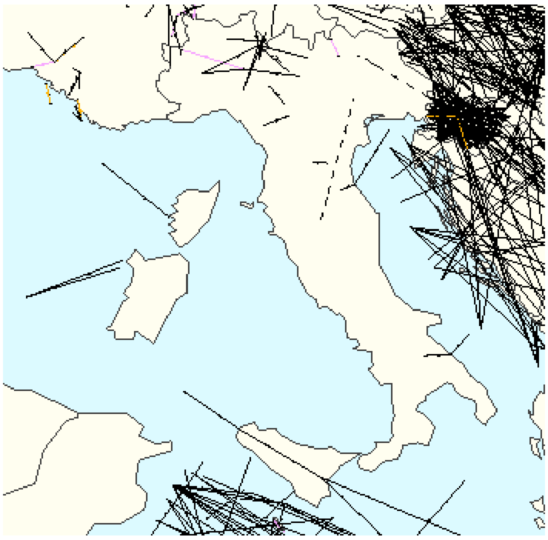

Figure 3.27 Italian daily DCT network

3.6.1. First case

The flights affected by this DTC are the ones that go from Spain to the Balkans, Rome or Pescara airports On the planned routes they cross the Italian airspace border with France at ELSAG, but when using the DCT the flights go without crossing this point from INKIR or OSPOK to TINTO or ROMPO depending on if they are operating in the Rome airport or not. In the following figure (figure 3.28) is reflected how the flights avoid performing the bend that planned route has by going straight using a DTC segment.

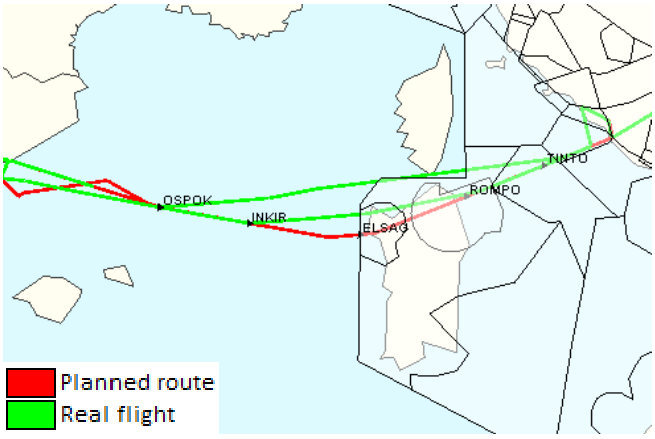

Figure 3.28 First case Italian airspace routes analysed

The figure above shows the two most common DCTs used, although more options are carried out in this segment. In spite of the fact that these are DCT that only involve two countries and are performed in the middle of the sea, only less than the 50% flights that overfly these airways do it. The daily frequency of these type of flights is of 20 in average.

3.6.1.1. ANSP costs

In this case we have to distinguish between the direct between INKIR and ROMPO and the one between OSPOK and TINTO because the cost savings are considerably different, more than three times higher for the longer one. Moreover, the operating costs also differ because as the INKIR- ROMPO case is for flights which use the Rome airport, the amount of NM overflying Italy is lower implying less en-route charges.

Table 3.10 First DCT Case Italian airspace charges analysis, ROMPO to INKIR

	Total (€)	Mean per flight (€)
Charges applicable to the planned flight	29464,74	589,29
Charges applicable to the performed flight	28811,28	576,22
Charges Savings	653,46	13,06

Table 3.11 First DCT Case Italian airspace charges analysis, TINTO to OSPOK

	Total (€)	Mean per flight (€)
Charges applicable to the planned flight	43612,06	872,24
Charges applicable to the performed flight	41346,09	826,92
Charges Savings	2265,97	45,31

3.6.1.2. Proposal

The best solution applicable for this route would be to set two DCT segments with one common starting point, OSPOK. Although the ATCOs usually give the DTC with INKIR as start to the planes operating at the Rome airport, the air-segment would go from OSPOK to ROMPO to in order to offer a longer and more efficient DCT. So as to implement this DCT, a new entry point should be created in the Italian airspace border with France (ITFRS).

The other DCT segment has a more difficult application, this is because it changes of airspace twice during its course. One feasible solution and the most efficient one would be to create one entry point (ITFRN) and inform to the French ATCOs that control the airspace to hand over the airplane once crossed this point. However, if this would not be possible a different entry point should be added (ITFRM) and the proposed DTC should be a little bit curved. The proposals previously explained are showed in the next figure (figure 3.29):

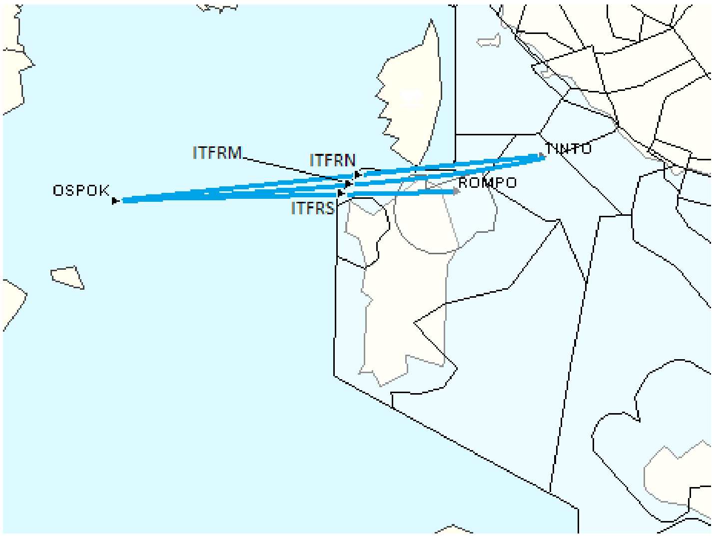

Figure 3.29 First case Italian airspace DCT proposal

3.6.2. Second Case

The routes affected by this DTC are the ones going from Central or North Europe to South Europe (Italy, France and Spain), these flights go from Germany to Italy overflying Austria. The exit point planned on the Austrian border with Italy is OLPIX and the flightplan follow the airways in Austria coming from the entry point of Austria on the German border TULSI. However, as the following figure shows (figure 3.30), commonly the DTC used goes straight to LUSIL starting from TULSI, which is a NAV point in the German airspace, instead of crossing at OLPIX.

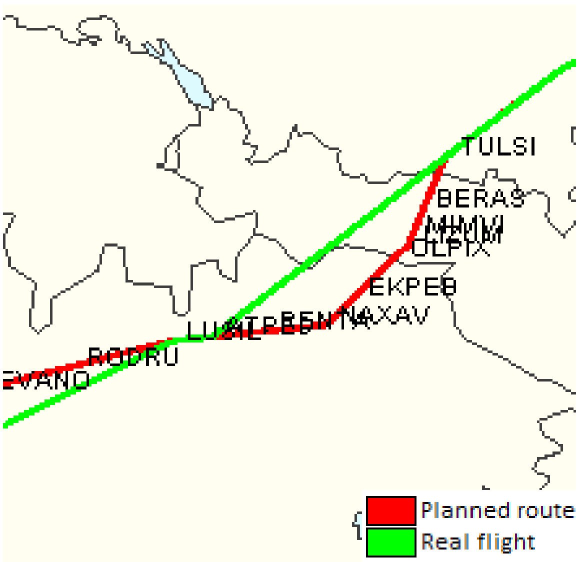

Figure 3.30 Second case Italian airspace route analysed

More than 30 flights a day follow this route and almost all of them make use of a DCT, about a 95%. Indeed there are less optimum DCT variations performed, as some that end at NAV points of the Austrian airspace, although the most efficient is the one in the previous figure.

3.6.2.1. ANSP costs

As the maximum optimization is the objective of the project the ANS charges and savings are only calculated with the most profitable option. As a small part of the DCT overflies Germany, its charges are also considered in the computations of the route cost.

Table 3.12 Second DCT Case Italian airspace charges analysis

	Total (€)	Mean per flight (€)
Charges applicable to the planned flight	31091,02	621,82
Charges applicable to the performed flight	30120,42	602,40
Charges Savings	970,59	19,41

3.6.2.2. Proposal

For this case there is no better solution that to follow what the most efficient DCT given by the ATCOs does. In order to implement it, an entry point in the Italian border has to be set, the DCT segment will cross through it having as endings TULSI and LUSIL. It is needed to say that in this situation a new point does not have to be created because it already exist an entry point in a useful location GIRIS for this proposal, as shown in the next figure (figure 3.31)

Figure 3.31 Second case Italian airspace DCT proposal

CHAPTER 4. VALIDATION

After studying and proposing several DCTs changing the entry point, it has to be checked if the solutions suggested are feasible and more optimum than the existing ones. In order to do that, first of all, all the new entry points and air-segments proposed have to be introduced in the network. Once done it, with help of the NEST function “Assignment”, explained in section 2.3.4, try the new network to see if from the provided network and different traffic files NEST suggests to use the DCTs proposed, which are supposed to enable shorter and more efficient routes than the existing ones in every case.

The result as expected for all the traffic files tested (10/03/2016, 21/02/2016, and 30/03/2016) is positive. The NEST tool chooses the new DCTs proposed instead of the old airways in almost all the flights that previously didn’t use it. The following figure (figure 1.33) shows an example where the route chosen by NEST overflies the new entry point, ITFRN, in the Italian airspace while doing the DCT proposed:

Figure 4.1 Example of Italian first case chosen by the assignment of NEST

NEST is demonstrating that the proposals done in this project are theoretically possible. Besides, as the information is extracted from real traffic data it means that similar DCTs have been performed under certain capacity conditions. These two considerations seem give reasons for its immediate introduction in the DCT network. However, for its full implementation, it has to be allowed the introduction of these DCTs in some flightplans in order to make tests with real traffic. Once introduced these proposals, airspace users would save costs in the en-route charges, an estimated summary of them is shown in the following table (table 4.1):

Table 4.1 Summary table of savings

Country	Case	Average number of flights	Average savings per flight (€)	Total savings per case (€)
Slovakia	First	24	18,34	440,16
	Second	15	19,61	294,15
Poland	First	70	35,24	2466,8
	Second	75	7,94	595,5
Germany	First	27	12,66	341,82
	Second	65	41,75	2713,75
Switzerland	First	37	38,7	1431,9
	Second	35	12,28	429,8
	Third	35	27,63	967,05
Italy	First short	10	13,6	136
	First long	10	45,31	453,1
	Second	30	19,41	582,3
			Total Daily Savings	10852,33

CONCLUSIONS

Once completed the development of this final degree project, it is necessary to synthesize all that has resulted from its realization. Beginning with conclusions obtained in the process to achieve the initial objective: evaluate the economic effect and the charges difference in cross-border operations between the use of DCTs and conventional routing.

First of all while doing the task aimed to find cross-border DCTs, it has been found by means of the traffic data analyzed with the NEST software that thousands of all DCTs types are performed everyday along the European airspace. However, only a few of them are published in the DCT networks of each country. This situation suppose an unneeded extra workload to the ATCOs due to the necessity to give clearance to pilots in order to do them, which if these DCTs would be set in the AIPs would not exist having only the need to ensure the safety of this operations.

Moreover, now focusing only on the cross-border DCTs, it is needed to say that, despite of the fact that these operations involve a high coordination between ANSPs, cross-border DCTs are performed every day in almost all the European countries. In this case the amount them published is even much lower than the ones performed within a country, almost negligible, only with the exception of the countries constituting the MUAC. The cross-border DCTs increase even more the workload of the ATCOs due to the need of coordination, so publishing this type of DCTs would also be beneficial for them.

After considering the increase on capacity that would be obtained due to the reduction of ATCOs workload if more DCTs were published in the AIPs, it has to be mentioned the economic effects that would imply the introduction of cross-border DCTs in the route network.

The assessment of more than 30 different cross-border DCTs has revealed that in most of the cases their publication would mean a significative deduction in the en-route air navigation charges. There are some cases which are not exposed in the main analysis which their implementation would imply a small loss or a small benefit, less than three euros in both cases. However, its implementation would be obviously profitable in terms of fuel and time savings, besides the environmental benefit.

As can be seen in the table 4.1, if only the proposed cases would be implemented, airspace users could save more than 10000€ every day. It means that a deeper investigation with all the cross-border DCTs done in Europe would achieve huge savings for the airspace users. Nevertheless, this improvement would signify losses for the ANSPs. Therefore, an intermediate solution that could satisfy both parties should be found, my proposal would be to increase the charges of the DCTs that imply cross-border operations in order to maintain the charges billed with the conventional routing. Applying this solution, the airspace users would pay the same charges for overflying airspaces but they would save fuel and time which are the main concern of current commercial aviation.

In my opinion obtained after all the research, there is a lack of cooperation between the airspace stakeholders (different ANSPs in Europe, airspace users, European organisations, etc.) in issues like the publication of DCT networks. It is what is slowing the European airspace modernization and with it the economic benefits that these improvements would suppose.

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ANNEX

ANNEX A. FLIGHTS EXEMPT FROM THE PAYMENT OF EN-ROUTE CHARGES[10]

- Flights performed by aircraft of which the maximum take-off weight authorised is less than two (2) metric tons.

- Flights performed exclusively for the transport, on official mission, of the reigning Monarch and his/her immediate family, Heads of State, Heads of Government, and Government Ministers.

- Search and rescue flights authorised by the appropriate competent body.

- Military flights performed by military aircraft of any State.

- Training flights performed exclusively for the purpose of obtaining a licence, or a rating in the case of cockpit flight crew, and where this is substantiated by an appropriate remark on the flight plan. Flights must be performed solely within this charging zone. Flights must not serve for the transport of passengers and/or cargo, nor for positioning or ferrying of the aircraft.

- Flights performed exclusively for the purpose of checking or testing equipment used or intended to be used as ground aids to air navigation, excluding positioning flights by the aircraft concerned.

- Flights terminating at the aerodrome from which the aircraft has taken off and during which no intermediate landing has been made (circular flights).

- Flights performed exclusively under VFR within this charging zone.

- Humanitarian flights authorized by the appropriate competent body.

- Customs and police flights.

ANNEX B. UNIT RATES OF THE EN-ROUTE CHARGES

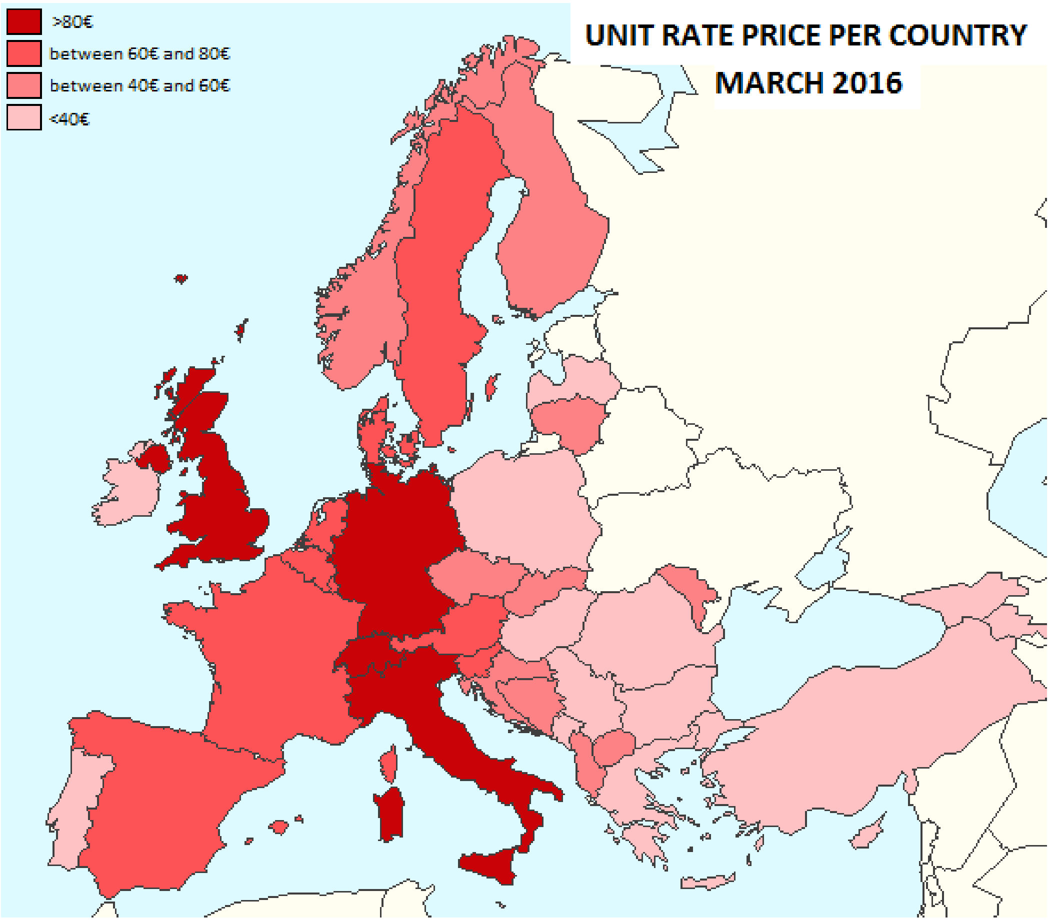

Figure B.1 European map of the unit rate charges prices of March 2016 [20]

Table B.1 Unit rates of route charges applicable to March 2016 [20]

Zone	Unit rate (€)
Switzerland	103,39
United Kingdom	94,05
Germany	82,68
Italy	80,17
Austria	73,72
Spain-Continent	71,78
France	67,63
The Netherlands	67,09
Belgium-Luxembourg	65,5
Slovenia	65,47
Denmark	61,74
Sweden	61,7
Spain-Canarias	58,45
Finland	56,32
Slovakia	52,63
Macedonia	52,48
Croatia	47,13
Albania	45,67
Lithuania	44,99
Czech Republic	43,06
Bosnia Herzegovina	41,92
Moldova	41,06
Norway	40,03
Portugal-Lisbon	39,99
Armenia	38,41
Serbia and Montenegro	37,02
Romania	36,41
Greece	36,11
Hungary	35,16
Cyprus	33,66
Poland	33,19
Ireland	29,76
Latvia	27,4
Malta	25,88
Turkey	25,25
Bulgaria	22,68
Georgia	22,05
Portugal-Santa Maria	10,89

ANNEX C. FREE ROUTE AIRSPACE IMPLEMENTATION

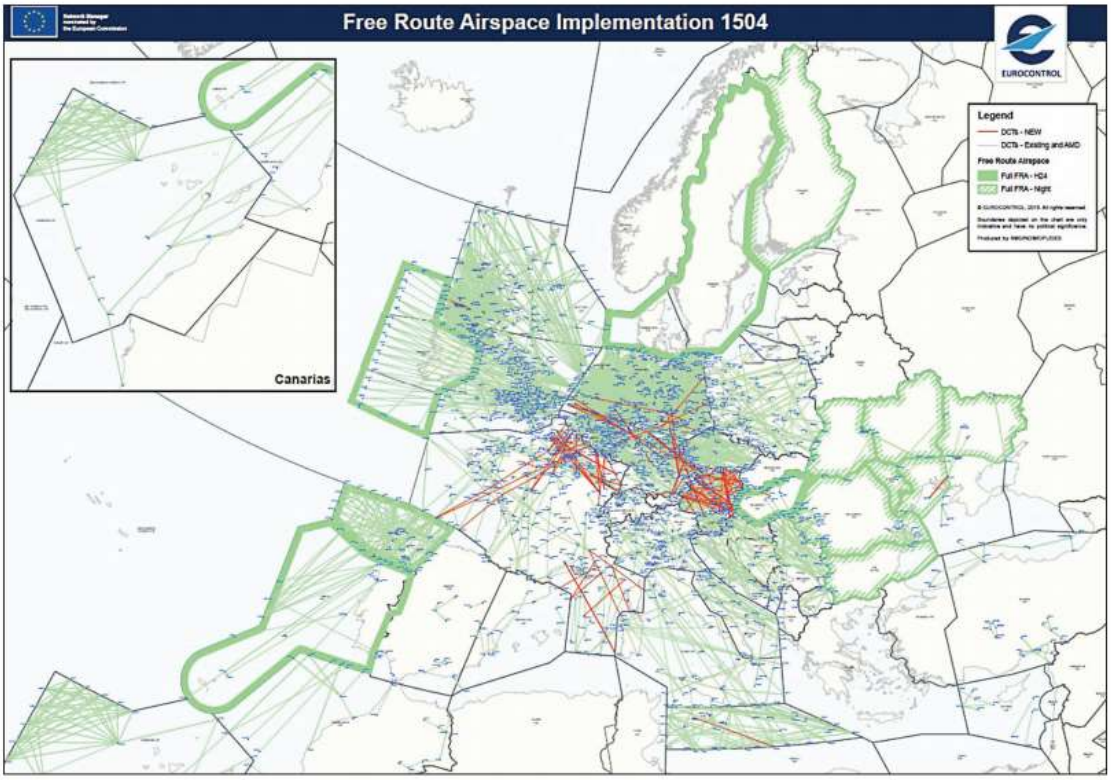

Figure C.1 Last updated map of the Free Route Airspace Implementation, April 2015 [21]

Table C.1 Last update of the ACCs with full or partial implementation of the Free Route Airspace (April 2015) [21].

Full Free Route Airspace implementation	Within Lisbon ACC and within Budapest ACC
	Within Kobenhavn ACC, Malmo ACC and Stockholm ACC as part of SWE/DNK FAB
	Within Shannon ACC/UAC as part of the ENSURE - EN-route Shannon Upper Airspace Redesign project
Full Night Free Route Airspace implementation	Within Sofia ACC
	Within Chisinau ACC
	Within Bucuresti ACC
	Within Tampere ACC
DCT implementation (Night-, Weekend-, H24 DCTs)	Within Maastricht UAC as part of FRAM – Free Route Airspace Maastricht
	Within Karlsruhe UAC as part of FRAK – Free Route Airspace Karlsruhe
	Between Maastricht UAC and Karlsruhe UAC as part of FRAMaK – Free Route Airspace Maastricht and Karlsruhe (cross-border)
	Within Wien ACC
	Within Zagreb, Beograd ACC AoR (including Montenegro and Bosnia & Herzegovina)
	Within Skopje ACC
	Within Ljubljana ACC
	Within Madrid ACC (SAN and ASI sectors) as part of the FRASAI project
	Within Malta ACC
DCT implementation (Night DCTs)	Within Milano, Padova, Roma, Brindisi and Praha ACCs
Limited DCT implementation (Night DCTs)	Within Reims, Brest, Bordeaux, Marseille ACCs and Warsaw ACCs
	New Night Time Fuel Saving Routes within London, Prestwick, Part Milano, Roma & Brindisi ACCs